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Working paper containing remarks of Dr. Shigeji Suyehiro, the Japan Meteorological Agency, concerning the usefulness of the employment of ocean-bottom seismographs and a universally acceptable means of determining the magnitude of seismic events, presented at the Informal Meeting on 30 June 1971

Introduction

Two topics will be discussed in connexion with the seismological approach to the detection and identification of underground nuclear explosions. The first topic is the employment of ocean-bottom seismographs to improve our present detection capability for seismic events and possibly to increase the capability of identifying explosions from natural events as well. The second concerns a possible and universally acceptable means of determining the magnitude of seismic events.

Detection and identification of seismic events

Great efforts have been made to evaluate the present detection capability for seismic events at teleseismic distances and also to ascertain the extent to which one can apply the identification criteria. In the Report of the SIPRI Seismic Study Group it was reported that the identification criterion, using the ratio of surface wave magnitude to body wave magnitude, is valid to a figure of 4.75 in body wave magnitude. Subsequent studies revealed that this criterion remains valid for events down to about 4.0. An encouraging paper has been produced by American scientists, reporting that events of even smaller magnitude, about 3.5, may still be identified by the same criterion. This means that a hardrock nuclear explosion of less than 1 kiloton could be identified, if we were able to detect it and obtain sufficient data from it for the criterion to be applied.

In addition to the identification criterion of surface wave to body wave, other criteria which depend solely on body waves are now being developed. In Japan, we are pursuing a study of the energy ratio of high frequency to low frequency in P waves to see if this can be used as a positive discriminant and the results are promising at

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teleseismic distances. If results attained so far are borne out by further studies, it will certainly lower the present identification threshold at teleseismic distances, since detecting surface waves, necessary for the application of the criterion of Ms : mb, is at the moment more difficult than detecting body waves. It is also reported that similar studies using P waves alone at short distances are in progress in the United States.

All these recent studies indicate that we have already acquired, or are about to acquire, techniques for discriminating between natural earthquakes and explosions valid to a considerably smaller magnitude range, if sufficient data is made available. And, once our data acquisition system is sufficiently improved to make the identification capability for such small events practical, seismological verification will contribute much more than is possible at present to the conclusion of a treaty to limit or ban underground nuclear weapons tests. To achieve this, our detection techniques must be improved to match the level of identification techniques.

A recent study by our American colleagues using an improved high-gain, long-period seismograph system is encouraging. According to the report, a considerable enhancement is expected in the detection of Rayleigh waves. Yet, our detection capability and azimuthal coverage have definite limits if we depend on teleseismic observation and confine ourselves to the land and a small number of islands. These limits will be substantially lowered if we can extend our systems by placing stations on the ocean floor which accounts for 70 per cent of the earth's surface.

Our recent observations off the Pacific coast of Japan using ocean-bottom seismographs showed that the background noise level at the site is only 1.0 to 1.5 millimicrons in a frequency range 2 to 10 cps, which is less than half that of the quietest land sites. This quietness is neither affected by weather nor is subject to seasonal changes. We fired 1 kilogram of dynamite in the water, and Pn wave from the explosion was clearly recorded at a distance of 100 km. If we apply the empirical law that the recordable distance is proportional to the square root of the amount of explosive, a 1 ton explosion in water should be recordable at a distance of 3,000 km. Background noise at the ocean bottom is naturally higher in the lower frequency range because of microseisms. The extremely low level of background noise in a range 2 to 10 cps, however, should not be overlooked, bearing in mind the fact that the P wave energy from underground explosions inclines toward a higher frequency range as compared with the energy from natural earthquakes.

The instrumentation of our present ocean-bottom seismographs is such that we can send them down to the sea floor to depths of several thousand meters and operate them for a period of 2 to 5 months without maintenance, if we so wish. And, the information stored on magnetic tape can be processed in a very short time. We will require more sophisticated instrumentation to handle a long period pendulum. But, even such an experiment is not technically impossible.

Taking the above points into consideration, it is believed that as far as signal-to-noise ratio is concerned even a single ocean-bottom station would serve to detect seismic events equivalent to a fairly large array station on land. If one could further set up a tripartite array at the ocean-bottom, it would have a certain independent location capability. With the development of identification criteria which use only P waves it will also provide data useful for identification.

We can obtain seismological access to areas exposed to the sea from under the high seas and without intruding into sovereign territory. It is, of course, difficult to obtain data from ocean-bottom seismographs on a real time basis. However, we can use them in such a way that we can bring them to the surface and examine the records only when necessary. Since ocean-bottom stations have such definite merits, it is suggested that we should not exclude the ocean-bottom seismograph from consideration when we contemplate improving or making changes in the global seismological network in the future.

Determination of magnitude

Let us suppose that a threshold has been agreed upon, above which underground nuclear explosions are banned and that the verification of compliance with such an agreement is to be undertaken by seismological methods. As all of us are aware, such a threshold must be defined in terms of the size of seismic events, and we shall have to say whether an event is above or below the threshold. And, this decision would have to be acceptable to all parties as being scientifically valid or, if there is no sufficiently convincing scientific basis, would have to be a matter for international political agreement. Even if we do not establish a threshold, we have to be concerned about the means of determining magnitude, as long as we employ magnitude as a scale to estimate underground explosions.

Determining the magnitude of an earthquake is not like measuring a length or a weight. We have painfully experienced that the magnitude determined at station A can differ by as much as 1.0 from that determined at station B and that such a deviation

from the mean value is not only a function of station but varies depending on each source-station combination. How can we cope with the task using what is, in a sense, an ambiguous quantity? One way to do it is to employ the mean magnitude of many stations and the other is to designate a certain number of stations as key stations and to accept the magnitude at these stations a priori.

As to the first scheme, there is the question of how many stations are needed if the mean magnitude is to be statistically significant. It is generally accepted that the magnitude determined by a single station has a standard deviation of about 0.5. The standard deviation of the mean magnitude decreases in proportion to the inverse square root of the number of stations. If we take the mean of 25 stations, the standard deviation will be 0.1. Magnitudes of this accuracy should be accepted without serious objection.

The following table shows how many stations of the 44 WWSSN stations in Appendix 7 of the SIPRI Report and the 46-station SPZ Network in the Canadian Report of 1970 are found within 90° from the existing nuclear test sites. Stations operated by the nuclear Powers using a particular test site are not included in the number for that site.

Test site	Number of stations in WWSSN (SIPRI)	Number of stations in the 46-station network
Nevada	19	15
Sahara	28	17
Aleutian	26	28
Novaya Zemlya	28	24
Kazakh	26	26
Sinkiang	28	23
Mururoa	11	27

There are sufficient numbers of stations to give statistically significant magnitudes for seismic events in these regions if the event is recorded at all stations. Consequently, the next question is what is the magnitude threshold for earthquakes which can be detected at a distance of 90°. We assume that the minimum readable trace amplitude is 1 mm (peak to zero), the magnification at 1 sec period is 75 K, the amplitude attenuation follows Gutenberg's $B(\Delta)$ curve, that stations could register magnitudes as much as 0.5 below the mean value; then should an event be 5 1/4 in magnitude, it could be detected at all sensitive stations within 90°. Because the sensitivity of many stations is actually higher than assumed here and a safety factor of $dm = 0.5$ is given, this threshold magnitude of 5 1/4 is a conservative estimate.

A similar value was given in the Canadian Report as the identification threshold depending on the existing SPZ and LPZ networks. To obtain Rayleigh wave data for the discriminant of Ms : mb, the identification threshold must be set about 0.8 higher in magnitude than the detection threshold for seismic events. As a consequence, we can obtain sufficient data of P wave for magnitude determination of statistical significance.

On the other hand we have high hopes of lowering the detection threshold for Rayleigh waves to that of P waves owing to recent developments in long-period instrumentation. In this case, the identification threshold will also be lowered. At the same time, however, the number of stations required for detection, location and identification must be reduced. Accordingly the two sets each consisting of a relatively small number of stations used for minor events will be completely different for instance in the case of an event in Nevada and an event in Kazakh, since most Asian and Middle East stations near Kazakh are more than 90° from Nevada. What could we do when we have magnitudes with comparatively low statistical value derived from two such different sets of stations?

We could of course decide to accept them as a first approximation. But, if we wish to have higher accuracy, we must try to find the coefficient of station correction as a function of the station-source combination so as to compensate for the geophysical peculiarities of the earth. Such a task undertaken on a global basis would be tremendous. If, however, we limit the study to combinations of stations of the highest sensitivity and possible source regions of underground nuclear explosions, it should not be too difficult.

It may be most practical to agree to start with the first approximation and then to revise the method of magnitude determination as the study progresses. In any case, there is no doubt that such a comprehensive study achieved through international co-operation would also provide our academic community with valuable fundamental geophysical information.